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# Simulation of Industrial Coking - Phase 1

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## ABSTRACT

Two statistically designed experimental programs using an Appalachian and a Western Canadian coal blend were run in CANMET's 460mm (18 inch) movable wall oven. Factors included coal grind, moisture, oil addition, carbonization rate and final coke temperature. Coke quality parameters including CSR, coal charge characteristics and pressure generation were analyzed.

## 1. BACKGROUND

For a fixed coal blend in an industrial wet charged battery, there is limited means to control coke quality. It is desirable to determine the effect and magnitude coke plant operating conditions, i.e., bulk density, heating conditions have on coke quality parameters especially CSR. In this series of movable wall oven tests, in order to more realistically simulate industrial coke oven practice, oil additions were used to control bulk density in the 460 mm movable wall oven.

Movable wall oven tests are used to simulate the coking process of an industrial coke oven. Conditions are chosen such that the resultant coke shows similar properties to that produced in an industrial oven. At CANMET, the 460 mm movable wall oven is used to study wall and gas pressure and coke quality i.e. size, apparent specific gravity (ASG), cold and hot strength. For the 460 mm movable wall oven, the standard conditions used are as follows:

Coal Grind          80%-3mm
Coal Moisture       3.0-3.5%
Oven Bulk Density   817±8 kg/m³
ASTM Bulk Density   778 kg/m³
Constant Flue Temp. 1250°C
Carbonization Rate  34.3 mm/hr to 900°C
Push                3 hours after center temperature
                    reaches 950°C

The coal blend is dried to raise the ASTM bulk density to 778 kg/m³. This leads to the aim oven bulk density for the movable wall oven.

In an industrial oven where the coal moisture varies between 6% and 10%, the oven bulk density is unknown, so the ASTM bulk density is monitored. Oil additions are used to raise coal charge bulk density when the moisture is too high.

## 2. EXPERIMENTAL METHODS

Using a standard industrial Appalachian and equivalent rank Western Canadian coal blend, two sets of experiments were run by the Canadian Carbonization Research Association (CCRA) at CANMET. The conditions used are shown in Table I.

**Table I**

| FACTOR | LOW | HIGH |
|---|---|---|
| %-3mm | 75 | 85 |
| %H₂O | 3.5 | 9.0 |
| %Oil | 0.0 | 0.3 |
| Heating Rate to 900°C(mm/hr) | 25.4 | 34.3 |
| Final Center Temperature (°C) | 950 | 1100 |

If this program was run altering each variable one at a time, it would have taken 216 runs for each coal blend. Therefore, it was decided to run a two level fractional factorial of resolution five i.e. $2_V^{(5-1)}$. This allowed all main effects and two factor interactions to be revealed in 16 runs for each blend.

To estimate the error associated with the analysis, three additional tests using standard conditions were run to establish repeatability. Three tests using center conditions were also run to measure the response that occurs between the high and low conditions. The responses measured included:

a) coal charge properties -bulk density,
b) movable wall oven   -pressure (wall, gas), yield,
c) coke quality        -size, strength, reactivity, texture.

Other parameters used in this study included soak time, time to complete movable wall oven tests and coal rheology.

## 3. DATA ANALYSIS

### 3.1   Anova Analysis:

Anova analysis was performed on the resultant data. Because the input parameters vary around the aim values, it was decided to use the aim values for the Anova analysis. The difference between the aim and actual values was assumed to

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be measured in the final response. For each response there were potentially 15 causes, i.e., 5 main effects and 10 two factor interactions. Three factor interactions or higher were assumed to be negligible. The purpose of the Anova analysis was to determine which of the 15 causes contribute significantly to each response. Because there are 16 experimental runs with 5 main effects and 10 two factor interactions, there were no degrees of freedom available to calculate the model mean square error. The 3 center and 3 standard condition test runs were used separately to compute confidence intervals for each response. If the confidence interval included zero, then the factor was not significant in contributing to the response.

It would be expected that when using the standard or center conditions to determine which effects are responsible for the measured responses, the conclusions should be similar. However, due to differences between the aim and actual values for the movable wall oven test conditions, it was not possible to be conclusive. It was then decided that the best method to analyze the data was to perform regression analysis.

## 4.    Regression Analysis:

A stepwise regression procedure was used to analyze the data. For a model to be accepted, the following criterion was used:

a)    A 95% minimum confidence level for the model,
b)    A 95% minimum confidence level for the dependent variables,
c)    Model residuals to have a mean of zero, be normally distributed and be independent,
d)    Dependent variables are not to be significantly correlated with each other and,
e)    For each effect added to the model, there must be a corresponding decrease in the model root mean square error for the effect to be valid.

Besides the main effects and two factor interactions, other parameters of interest include:

a)    Soak Time: Defined as the difference between time to push and time for the charge to reach 950°C.
b)    Days: Defined as the number of days to perform the movable wall oven test work with the first movable wall oven test labelled zero.
c)    Coal Fluidity: It has been shown that coal charge fluidity will decrease with time, which can lead to a decrease in coke quality.
d)    Coal Dilation: It has been shown that coal charge dilation will decrease with time, which can lead to a decrease in coke quality.

All main effects were included along with soak time, days and coal rheology. Two factor interactions were included only if their main effects were significant.

Other statistical information of importance is:

a)    $R^2$ = Variance accounted for
b)    RMSE = Variance accounted for by the model in explaining the response.

Terms used in the regression analysis are defined as follows:

a) CoalH2O = Coal $H_2O$ (%)
b) Coal35 = Coal -3.5mm (%)
c) Oil = Oil addition (%)
d) FCTemp = Final Center Coke Temperature (°C)
e) HR900 = Coking Rate to 900°C (mm/hour)
f) Soaktime = Gross Coking Time-Time to 950°C (hour)
g) Fluid = Coal Blend Fluidity (ddpm)
h) Days = Time to perform movable wall oven tests (days)

## 5.  RESULTS

### 5.1    Main Effects:

All regressions were run with the above listed parameters. In the associated tables, only the factors that were significant are listed.

### 5.11    Bulk Density:

Regression analysis for bulk density is shown in Table II (Figure 1) for the Appalachian (App) and Western Canadian (WC) blends. The oil additions of 0.15% and 0.30% at 6% and 9% coal moisture, respectively, were not adequate in raising the ASTM bulk density to the standard 3.5% moisture of 778 kg/m³ or the oven bulk density to 817 kg/m³. Coal moisture was the predominant factor for both the ASTM and oven densities. The equations for both coal blends were similar, however, the effect of oil was more pronounced for the Western Canadian coal blend.
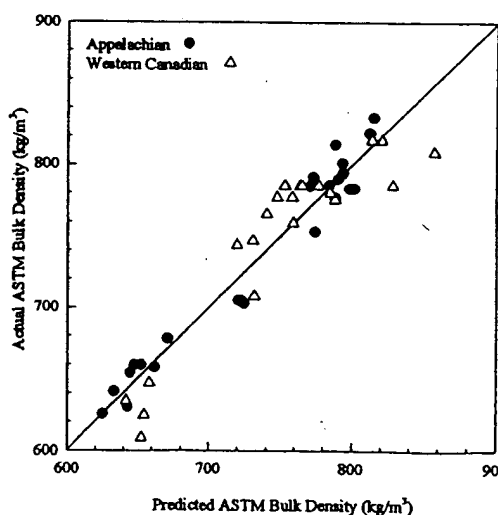


**Figure 1** Actual ASTM B.D versus Predicted ASTM B.D.

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## Table II Bulk Density Regression Results

| Parameter | Coal Blend | Intercept | CoalH2O | Coal35 | Oil | Days | Prob>F | RMSE | R² | Range |
|-----------|-----------|-----------|---------|--------|-----|------|--------|------|-----|-------|
| ASTM B.D. (kg/m³) | App | 1033.698 | -26.594 | -1.957 | 55.275 | -- | 0.0001 | 14.90 | 0.960 | 625.0-833.0 |
| | WC | 858.441 | -18.503 | -- | 219.953 | -0.806 | 0.0001 | 27.33 | 0.841 | 609.0-817.0 |
| Oven B.D. (kg/m³) | App | 913.879 | -23.691 | -- | -- | -- | 0.0001 | 8.12 | 0.983 | 697.0-852.0 |
| | WC | 898.223 | -18.596 | -- | 80.929 | -0.373 | 0.0001 | 14.91 | 0.926 | 705.0-846.9 |

## Table III Wall and Gas Pressure Regression Results

| Parameter | Coal Blend | Intercept | CoalH2O | Oil | Prob>F | RMSE | R² | Range (Not Log) |
|-----------|-----------|-----------|---------|-----|--------|------|-----|------|
| Log Max. Wall Pressure | App | 4.021 | -0.349 | -- | 0.0001 | 0.382 | 0.853 | 0.32-4.01 |
| | WC | 2.720 | -0.175 | 0.883 | 0.0001 | 0.214 | 0.827 | 0.44-2.04 |
| Log Max. Gas Pressure | App | 5.619 | -0.550 | -- | 0.0001 | 0.377 | 0.937 | 0.20-13.08 |
| | WC | 2.534 | -0.313 | -- | 0.0050 | 0.909 | 0.398 | 0.07-2.25 |

## 5.12   Pressure:

Regression analysis for wall and gas pressure is shown in Table III. At coal blend moisture of 3.5%, the Western Canadian coal blend produced wall and gas pressures much smaller than the Appalachian blend. At 6% and 9% coal moisture, there was no significant difference between the blends and the pressures were quite low (Figure 2). Coal moisture, hence charge bulk density will greatly influence wall and gas pressure generation for a given blend.
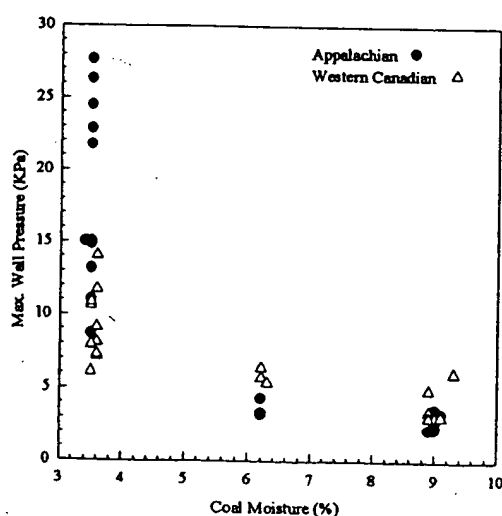
## 5.13   Apparent Specific Gravity:

Coke apparent specific gravity (ASG) is a measure of the structure and porosity of the product coke. Regression analysis for the Appalachian and Western Canadian coal blends are shown in Table III (Figure 3). Lower coal charge moisture, coarser grind, increased oil addition, i.e., higher bulk density, with an increase in final center temperature and slower carbonization rate to 900°C will result in a denser coke structure.



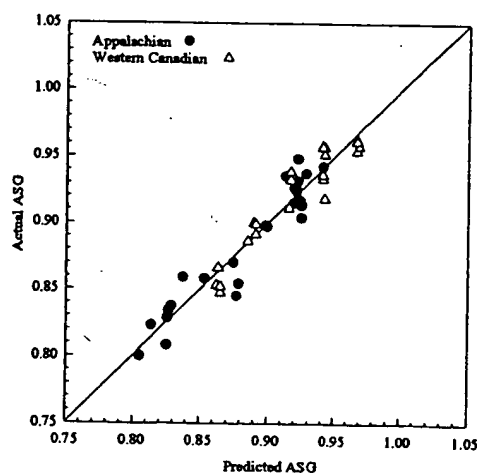Figure 2 Max. Wall Pressure versus Coal Moisture



Figure 3 Actual ASG versus Predicted ASG

For the range in the variables studied, bulk density had a greater influence on ASG than heating considerations for the Western Canadian blend. The effect of coal moisture was similar for both the Appalachian and Western Canadian

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**Table IV Apparent Specific Gravity Regression Results**

| Parameter | Coal Blend | Intercept | CoalH2O | Coal35 | Oil | FCTemp | HR900 | Prob>F | RMSE | R² | Range |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Apparent Specific Gravity (ASG) | App | 0.940 | -0.0148 | -0.0014 | -- | 0.00022 | -0.0026 | 0.0001 | 0.013 | 0.942 | 0.800-0.948 |
| | WC | 0.993 | -0.0144 | -- | 0.0881 | -- | -- | 0.0001 | 0.013 | 0.898 | 0.847-0.962 |

**Table V Coke Mean Size and Size Distribution Results**

| Parameter | Coal Blend | Intercept | CoalH2O | Oil | HR900 | Prob>F | RMSE | R² | Range |
|---|---|---|---|---|---|---|---|---|---|
| Mean Coke Size (mm) | App | 92.745 | 0.778 | -- | -1.206 | 0.0001 | 1.16 | 0.928 | 53.3-64.5 |
| | WC | 95.861 | -- | -6.060 | -1.244 | 0.0001 | 1.19 | 0.929 | 51.1-64.5 |
| +75mm (%) | App | 75.458 | 1.192 | -- | -2.005 | 0.0001 | 1.71 | 0.945 | 7.5-30.1 |
| | WC | 70.291 | -- | -- | -1.738 | 0.0001 | 2.97 | 0.810 | 8.5-30.6 |
| -75+50mm (%) | App | -- | -- | -- | -- | -- | -- | -- | 38.5-47.6 |
| | WC | 58.736 | -- | -- | -0.596 | 0.0001 | 1.94 | 0.540 | 35.2-45.7 |
| -25mm (%) | App | 0.995 | -- | -- | 0.123 | 0.0001 | 0.30 | 0.675 | 3.9-6.0 |
| | WC | 2.980 | 0.224 | -1.756 | 0.0771 | 0.0001 | 0.49 | 0.691 | 5.3-8.0 |

blends.

### 5.14 Coke Yield:

Regression analysis showed that no main effects interacted with yield results for either the Appalachian or Western Canadian blend. Since a constant coal blend was used in each series, i.e., constant blend volatile matter, this result would be expected.

### 5.15 Coke Size:

Regression analyses for mean coke size and size distributions are shown in Table V (Figure 4). Regression analysis showed that coke size was primarily controlled by the carbonization rate to 900°C along with the coal charge moisture. A slower carbonization rate will increase coke size. The heating rate coefficient was similar for both the Appalachian and Western Canadian blends.

### 5.16 Cold Coke Strength:

Coke cold strength was measure used the ASTM stability test and JIS test. Regression analyses for both the Appalachian and Western Canadian blend are shown in Table VI.

Regression analysis showed that stability was controlled by coal moisture, coal grind, final center temperature and carbonization rate to 900°C (Figure 5). Lower coal moisture, finer coal grind, higher final center temperature and slower carbonization rate to 900°C will lead to an increase in

stability. Regression coefficients were similar for both the Appalachian and Western Canadian blends.
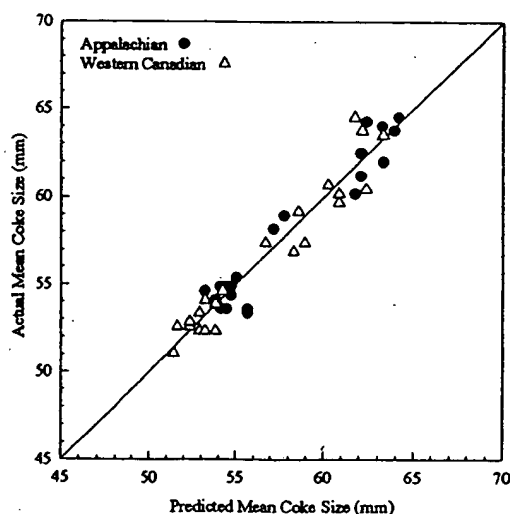


**Figure 4** Actual Mean Coke Size versus Predicted Mean Coke Size

Hardness was controlled by coal moisture, coal grind, final coke temperature of the coke and coal rheological properties. Lower coal charge moisture, coarser coal grind and higher final center temperature will lead to an increase in hardness. Any deterioration in coal rheological properties due to storage lowers hardness.

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## Table VI Cold Coke Strength Regression Results

| Parameter | Coal Blend | Intercept | CoalH2O | Coal35 | Oil | PCTemp | HR900 | Days | Prob>F | RMSE | R² | Range |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stability (%) | App | 52.484 | -1.067 | 0.098 | -- | 0.021 | -0.577 | -- | 0.0001 | 1.24 | 0.924 | 48.6-63.1 |
| | WC | 50.131 | -1.089 | 0.235 | -- | 0.017 | -0.786 | -0.060 | 0.0001 | 1.63 | 0.894 | 46.1-62.6 |
| Hardness (%) | App | 60.488 | -1.563 | -0.091 | -- | 0.021 | -- | -0.018 | 0.0001 | 0.660 | 0.980 | 57.8-70.7 |
| | WC | 77.005 | -1.422 | -- | -- | -- | -- | -0.084 | 0.0001 | 2.143 | 0.803 | 56.6-70.6 |
| DI30/15 (%) | App | 92.605 | -0.096 | 0.019 | -- | 0.0032 | -0.084 | -- | 0.0001 | 0.224 | 0.835 | 91.2-95.1 |
| | WC | 95.005 | -0.331 | -- | 2.116 | -- | -- | -- | 0.0001 | 0.611 | 0.684 | 90.8-94.7 |
| DI150/15 (%) | App | 83.400 | -0.470 | -- | -- | 0.0065 | -0.127 | -0.016 | 0.0001 | 0.497 | 0.917 | 79.7-84.9 |
| | WC | 77.900 | -0.852 | 0.089 | 4.492 | 0.0067 | -0.160 | -0.044 | 0.0001 | 0.873 | 0.927 | 75.5-85.5 |

## Table VIIa Coke Strength After Reaction Regression Results

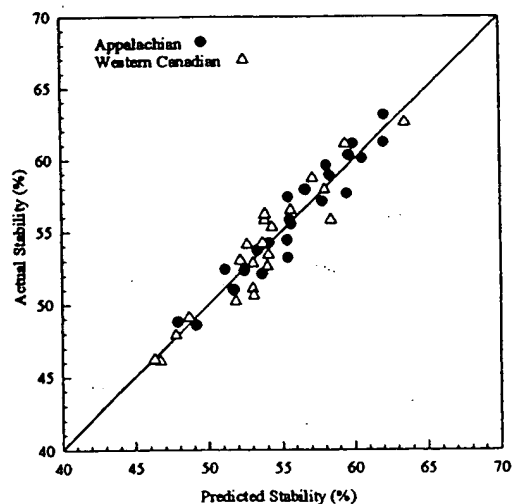| Parameter | Coal Blend | Intercept | CoalH2O | Oil | Days | Fluid | Prob>F | RMSE | R² | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| CSR (%) | App | 61.301 | -1.233 | -- | -- | -- | 0.0001 | 1.67 | 0.788 | 47.7-59.9 |
| | WC | 72.602 | -1.674 | 10.284 | -0.0985 | -- | 0.0001 | 2.61 | 0.811 | 48.9-66.1 |
| CRI (%) | App | 33.083 | 0.018 | -- | -- | -0.0033 | 0.0173 | 1.11 | 0.321 | 27.5-31.7 |
| | WC | 22.287 | 0.325 | -3.691 | 0.0401 | -- | 0.0001 | 0.808 | 0.759 | 23.2-28.3 |



**Figure 5** Actual Stability versus Predicted Stability

The JIS DI30/15 drum index test was also run for this series of movable wall oven tests. The DI30/15 index was controlled by coal moisture, coal grind, final center temperature and carbonization rate to 900°C for the Appalachian blend. These were the same factors that controlled stability. The effect of carbonization rate to 900°C and final coke temperature did not enter the equation for the Western Canadian blend as with the Appalachian blend

regression. The effect of oil addition was more pronounced for the Western Canadian blend.

For the Appalachian blend, the DI150/15 was controlled by coal moisture, carbonization rate to 900°C, final center temperature and coal rheological properties. Lower coal moisture, slower carbonization rate to 900°C and higher final coke temperature will lead to an increase in DI150/15. Any deterioration in coal rheological properties due to storage time will lower DI150/15. For the Western Canadian blend, the regression coefficients were similar except that coal grind and oil additions were also significant.

### 5.17 Coke CSR/CRI:

Regression analysis for both the Appalachian and Western Canadian blend is shown in Table VIIa. With respect to CSR, for the Appalachian blend, coal moisture was significant. As shown graphically in Figure 6, each coal moisture level is distinct but within each level, no regressions were found to explain the data at the 5% level of significance.

Previous work by Canmet[2] has shown carbonization rate and soaktime both influence CSR, but those tests were run under constant coal moisture conditions, so the effect of charge bulk density was not considered. These effects could not be duplicated under the conditions used for this program. CRI did not show a high degree of variance accounted for. Coal charge moisture and to a minor extent coal fluidity were the only factors that could explain CRI. For the Western Canadian blend, the factors were similar. In addition, oil

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additions were significant for the Western Canadian blend. The CRI index was marginally affected by coal moisture in comparison to the CSR index. Deterioration in coal rheological properties affected CSR/CRI adversely. Because a constant coal blend was used for each series, these regressions did not take into account ash or ash chemistry as a factor affecting CSR/CRI.

Texture analysis was also performed on the resultant cokes. Regression analysis was performed between CSR/CRI and coke texture to determine if heating conditions used in this study would alter coke texture and consequently CSR/CRI. However, there were no significant regressions between CSR or CRI and coke texture for this study.

It should be noted that the CSR values were higher and CRI values lower for the Western Canadian blend over the Appalachian blend. This is mainly due to the lower ash basicity ratio of the Western Canadian blend.

demonstrate the importance of bulk density control. Increases in bulk density resulted in an increase in ASG, stability, hardness, DI and CSR. The CSR regression results are shown in Figure 7. Wall and gas pressure also increased. When bulk density was used in developing the CSR regression, carbonization rate to 900°C became significant for the Western Canadian blend. The effect of bulk density on coke parameters was similar for both the Appalachian and Western Canadian coal blends.
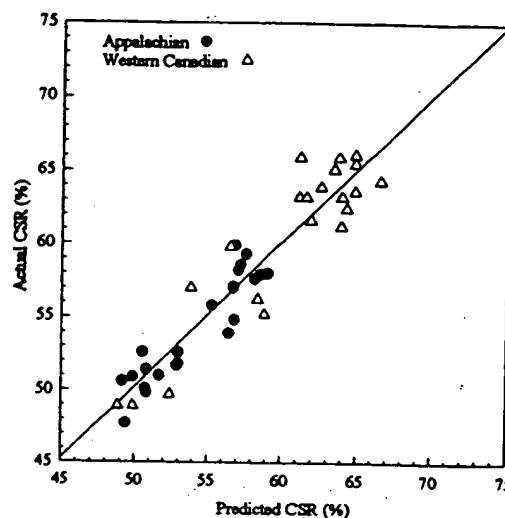


Figure 7 Actual CSR versus Predicted CSR



Figure 6  Actual CSR versus Predicted CSR

## 5.2   Charge Bulk Density:

Coal charge moisture negatively affects all coke quality parameters, i.e., strength, reactivity, except size. Higher coal charge moisture lead to lower gas and wall pressures. When coal charge moisture was increased, there was a decrease in charge bulk density, even when oil was added to the charge. Because of less particle contact and lower compaction of the charge, the resultant coke structure is expected to be more porous and mechanically weaker. The combined effects of coal moisture, coal grind and oil additions were combined into a single parameter, i.e., ASTM bulk density. Regressions were run again using ASTM bulk density along with the other main effects. If coal moisture did not figure in the original regressions, then no significant relationship with bulk density was expected. These results which are shown in TableVIIb

## 5.3   Coke ASG:

Coke ASG can be used to confirm coal charge bulk density and heating conditions. Because ASG is a fundamental measurement of coke structure, it is a common parameter that can relate coke quality parameters together. These relationships which are shown in TableVIII, were similar for both the Appalachian and Western Canadian coal blends. The relationships between ASG and log wall pressure, stability, hardness and CSR are shown in Figures 8-11.

An increase in ASG resulted in increased coke strength because of improved packing of the parent coal charge. However, the associated increase in bulk density resulted in higher wall and gas pressure.

At higher coal moisture levels because of decreased particle contact along with a lower compaction of the coal charge, the resulting coke structure is expected to be weaker and more porous. This is confirmed by the lower stability, DI index and CSR index.

CRI was not strongly related to charge bulk density to the same extent as CSR. At higher coal moisture, a lower ASG, stability and CSR indicated that the coke would be weaker

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**Table VIIb ASTM Bulk Density Regression Results**

| Parameter | Coal Blend | Intercept | ASTM B.D. | FCTemp | HR900 | Days | Prob>F | RMSE | R² |
|---|---|---|---|---|---|---|---|---|---|
| Log Max. Wall Pressure | App | -7.514 | 0.013 | -- | -- | -- | 0.0001 | 0.397 | 0.845 |
| | WC | -2.848 | 0.006 | -- | -- | -- | 0.0001 | 0.300 | 0.643 |
| Log Max. Gas Pressure | App | -12.054 | 0.020 | -- | -- | -- | 0.0001 | 0.458 | 0.904 |
| | WC | -6.338 | 0.010 | -- | -- | -- | 0.0001 | 1.007 | 0.262 |
| Apparent Specific Gravity (ASG) | App | 0.357 | 0.0006 | 0.00017 | -0.0021 | -- | 0.0001 | 0.010 | 0.963 |
| | WC | 0.526 | 0.0005 | -- | -- | -- | 0.0001 | 0.021 | 0.719 |
| Mean Coke Size (mm) | App | 120.193 | -0.030 | -- | -1.236 | -- | 0.0001 | 1.043 | 0.942 |
| | WC | 102.398 | -0.012 | -- | -1.196 | -- | 0.0001 | 1.251 | 0.923 |
| +75mm (%) | App | 119.643 | -0.048 | -- | -2.074 | -- | 0.0001 | 2.122 | 0.917 |
| | WC | 89.472 | -0.024 | -- | -1.782 | -- | 0.0001 | 2.602 | 0.861 |
| -75+25mm (%) | App | No Significant Regression | | | | | | | |
| | WC | 58.736 | -- | -- | -0.596 | -- | 0.0001 | 1.938 | 0.540 |
| -25mm (%) | App | 0.995 | -- | -- | 0.123 | -- | 0.0001 | 0.300 | 0.675 |
| | WC | 10.793 | -0.009 | -- | 0.079 | -- | 0.0001 | 0.497 | 0.660 |
| Stability (%) | App | 26.417 | 0.038 | 0.019 | -0.541 | -- | 0.0001 | 1.593 | 0.867 |
| | WC | 35.508 | 0.044 | -- | -0.489 | -- | 0.0001 | 2.873 | 0.610 |
| Hardness (%) | App | 7.658 | 0.058 | 0.015 | -- | -- | 0.0001 | 0.974 | 0.952 |
| | WC | 22.765 | 0.058 | -- | -- | -- | 0.0001 | 1.972 | 0.793 |
| DI30/15 (%) | App | 91.701 | 0.003 | 0.0032 | -0.086 | -- | 0.0001 | 0.279 | 0.729 |
| | WC | 83.021 | 0.014 | -- | -- | -- | 0.0001 | 0.570 | 0.711 |
| DI15015 (%) | App | 73.537 | 0.017 | -- | -0.110 | -- | 0.0001 | 0.729 | 0.800 |
| | WC | 52.550 | 0.038 | -- | -- | -- | 0.0001 | 1.310 | 0.782 |
| CSR (%) | App | 19.247 | 0.048 | -- | -- | -- | 0.0001 | 1.443 | 0.849 |
| | WC | -12.409 | 0.081 | -- | 0.401 | -- | 0.0001 | 2.149 | 0.865 |
| CRI (%) | App | 36.060 | -0.0085 | -- | -- | -- | 0.0292 | 1.186 | 0.207 |
| | WC | 42.437 | -0.0175 | -0.0050 | -- | 0.023 | 0.0001 | 0.574 | 0.879 |

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## Table VIII ASG Regression Relationships

| Parameter | Coal Blend | Intercept | ASG | Prob>F | RMSE | R² |
|---|---|---|---|---|---|---|
| Log Max. Wall Pressure | App | -14.347 | 18.574 | 0.0001 | 0.474 | 0.779 |
| | WC | -8.678 | 11.404 | 0.0001 | 0.206 | 0.832 |
| Log Max. Gas Pressure | App | -22.547 | 28.346 | 0.0001 | 0.590 | 0.841 |
| | WC | -15.937 | 18.158 | 0.0092 | 0.942 | 0.354 |
| Mean Coke Size (mm) | App | No Significant Regression | | | | |
| | WC | No Significant Regression | | | | |
| Stability (%) | App | -13.894 | 79.584 | 0.0001 | 1.860 | 0.801 |
| | WC | -29.228 | 90.219 | 0.0001 | 2.639 | 0.654 |
| Hardness (%) | App | -14.905 | 90.536 | 0.0001 | 1.373 | 0.905 |
| | WC | -27.124 | 101.011 | 0.0001 | 2.379 | 0.745 |
| DI30/15 (%) | App | 87.727 | 7.200 | 0.0010 | 0.411 | 0.412 |
| | WC | 73.480 | 22.683 | 0.0001 | 0.539 | 0.742 |
| DI15015 (%) | App | 56.506 | 29.386 | 0.0001 | 0.847 | 0.733 |
| | WC | 23.593 | 62.609 | 0.0001 | 1.230 | 0.807 |
| CSR (%) | App | -5.623 | 67.837 | 0.0001 | 1.636 | 0.798 |
| | WC | -50.410 | 120.821 | 0.0001 | 2.987 | 0.726 |
| CRI (%) | App | No Significant Regression | | | | |
| | WC | 49.635 | -26.700 | 0.0004 | 1.136 | 0.472 |



**Figure 8** Log Max. Wall Pressure versus ASG



**Figure 9** Stability versus ASG

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**Figure 10** Hardness versus ASG



**Figure 11** CSR versus ASG

Regression results and the associated coefficients were ISB0086 to be very similar for both the Appalachian and Western Canadian coal blends. When the two regression lines were plotted on the same graph, the resulting equations were superimposed on top of each other. The major differences between the responses obtained with the Appalachian and Western Canadian coal blend was that the Western Canadian coal blend was more sensitive to oil addition and storage time.

For both blends, regression analysis showed that CSR and CRI were dependent upon charge bulk density as shown by the inclusion of coal moisture and oil in the regression equations. Carbonization rate to 900°C and soak time did not enter these regressions when coal moisture, grind and oil addition were used. When these terms were grouped into a single term, i.e., ASTM bulk density, carbonization rate to 900°C became significant. Deterioration of coal rheological properties affected CSR and CRI adversely. Since the objective of this study was to investigate the affect of coking conditions on coke quality, these regressions did not take into account coke ash chemistry as a factor effecting CSR or CRI. There were no valid regressions between coke texture and CSR or CRI.

The effect that charge moisture and bulk density has on the resultant coke quality parameters as well as the importance of ASG as control parameter was demonstrated.

## 7. INDUSTRIAL APPLICATIONS

There has been an ongoing study at Dofasco to measure and reduce the variation of cokemaking parameters that affect coke quality. Key parameters based on this CCRA program are:

- coal moisture,
- coal bulk density,
- carbonization rate and
- final coke temperature.

Dofasco has taken an approach to understand how these cokemaking parameters effect coke quality by:

- developing appropriate measurement systems,
- performing R and R studies on the developed measurement systems and
- identifying and quantifying sources of variation.

Specific developments are as follows:

- Moisture: Dofasco stockpiles component coals during the winter months. A slower heating rate during the winter months is required to compensate for the resulting high coal blend moisture. It was recognized that compensation would have to be made for a lower coal charge bulk density. Coal blend strategy was changed to ensure that maximum coke strength potential blends are utilized during the winter months to compensate for high coal blend moisture.

prior to reaction with $CO_2$, therefore a lower CSR value would be expected independent of CRI.

## 6. DISCUSSION

The conditions chosen were thought to realistically simulate actual conditions in an industrial oven, especially using oil additions to control bulk density. For both the Appalachian and Western Canadian coal blends, significant regression results using the experimental factors were developed for ASTM bulk density, oven bulk density, wall and gas pressure, coke ASG, coke size and size distribution, stability, hardness, DI30/15, DI150/15, CSR and CRI.

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• Bulk Density Control: In coal preparation, all critical parameters were evaluated, i.e., blending, bulk density, coal grind and oil additions. Control plans were implemented for bulk density control, blending and coal contamination. Control charts and reaction plans were developed for correcting out of control situations.

• Heating Control: The critical carbonization factors, i.e., carbonization rate, final center temperature and soak time are indirectly controlled by the flue temperature system and the maintenance of a consistent pushing schedule. In addition, the critical factors cannot be directly measured inside the coke oven. In lieu of this fact, Dofasco has developed additional measuring systems to aid in detecting critical carbonization factors:

    • Final coke temperature measuring equipment has been installed at the entrance of the quench stations for all three coke plants. This along with the flue temperature monitoring system is used to determine if the coke product has had an adequate coking time. During times of high coal moisture, if the final coke temperature drops, the coke plants now take a delay in pushing to compensate for inadequate coke out. Microwave analyzers are being installed in coal handling to allow increased frequency of coal blend moisture measurement.

    • At Dofasco, coke ASG is measured routinely and is used as a tool to determine if a problem with coking conditions. Indirectly, it can rule out coal as a source of a quality problem. Increased variability in ASG results can indicate inconsistent heating conditions which may lead to lower coke quality. In addition, a coke texture analysis is also performed to gain insight about heating conditions.

## 8. FUTURE WORK

Most coke strength models in the literature are based primarily on coal petrographic properties. Most CSR models are based on coal chemical, rheological and or petrographic properties. Usually, modeling both these coke properties involves using constant standard movable wall oven conditions. However, neither of these two coke quality parameters have been modeled using both coal properties and coking conditions together. For coke properties like coke size and stability, coking conditions are the most significant factors because the coal properties required, especially for stability, are fixed in a very specific range. This is not necessarily true for coke CSR. If stability is fixed at 60% or greater, coke CSR can vary dramatically depending on the coal ash and ash chemistry, coal rheology, coal petrography and coking conditions used. By combining coal properties and coking conditions together in one experimental design, we will be able to better understand the interrelationship that exists between them and their combined effect on final coke quality. Factors include coal charge bulk density, carbonization rate to 900°C, final center temperature, coal rank, coal rheology and

coal ash chemistry. Experimental work is underway and results should be ready early next year.

## 9. CONCLUSIONS

1) Under the conditions used, coal moisture was found to influence all responses measured. Increased coal moisture resulted in a decrease in charge bulk density, strength, ASG, CSR and wall and gas pressures.

2) Oil additions were not effective in maintaining charge bulk densities at higher moisture levels.

3) Slower carbonization rate resulted in increased coke size, strength and ASG.

4) Higher final coke temperature resulted in marginal increases in coke strength and coke ASG.

5) Coke texture could not be explained by the heating conditions used.

6) Responses to changes in coking conditions were similar for the Western Canadian and Appalachian coal blends.

## ACKNOWLEDGMENTS

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